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On Sediment Pollution in Selected German Coastal Waters of the Baltic Sea

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With one Figure and 4 Tables

Key words: Sediment quality, harmful substances, regional pollution, target values, Baltic Sea

Abstract

In order to determine and assess their status sediments from the German coastal waters of the baltic sea were analyzed for structural parameters and for several groups of harmful substances. Regarding all groups of harmful substances, i.e. nutrients, heavy metals and organic toxicants the sediments of the eastern sections investigated (Strelasund, Peenestrom and Stettin Lagoon) are generally more polluted than the sediments of the other ones.

The sediments of the examined sections of the Baltic coast compare with North Sea sediments by factors of between 0.05 and 4 with regard to heavy metals.

Because of the variability of the concentration of harmful substances in the various coastal sections, it is imperative to make a differentiated assessment of the polluted sediments and to set district-related targets for the various sections of the Baltic coast.

Introduction

The investigations are aimed at obtaining the sediment status of the federal waterways in Baltic Sea coastal waters, at determining sources of harmful substances, at assessing their nature, and at evaluating the potential risk of sediment transport. Sediments and suspended matter include a major part of several priority harmful substances. Hence, there is general consensus that quality criteria for the assessment of sediments and suspended matter should be developed.

Obtaining natural background data is difficult due to such effects as soil reactions, metabolizing, bioaccumulation, and bioturbation. Consequently, in addition to the natural background data current data on regional pollution are of great importance in sediment assessment (HELCOM 1993; BRÜGMANN 1995).

Concentrations of harmful substances in different sections of the Baltic coast are known from various references. Direct comparisons, however, are difficult to make since the investigations cover different grain size fractions as well as bioavailable components or total contents, respectively.

Therefore, since 1991, the Berlin branch of the Federal Institute of Hydrology (BfG) has been examining sediments from various sections of coastal waters, from the Wismarbucht to the Stettin Lagoon (MÜLLER et al. 1995).

The compilation of representative data on the current pollution of surface sediments shall provide the basis for developing a standard of assessment allowing to deduce quality targets, without neglecting the acquisition of data on the natural background.

District of examination

The Baltic coast has manifold features, including boddens (land-locked coastal waters) and haffs. The bottom of the coastal districts of the Baltic Sea is characterized by Holocene deposits, especially late Glacial marly till, which, in the deposition zones, is covered with recent, terrigenous silt.

Compared with the North Sea, the Baltic Sea has less interaction with the Atlantic Ocean, lower salinity, reduced tidal effects, and a higher eutrophication potential. As a result, differentiated ecosystems have emerged along the Baltic coast.

Anthropogenic effects at the German coast are caused by the shipyard and seaport cities of Kiel, Lübeck, Wismar, Rostock, Stralsund, and Wolgast, and also by agriculture, which is a major sector of the economies in Schleswig-Holstein and Mecklenburg-Western Pomerania. The status of the rivers Trave, Peene, and Oder, for instance, will reflect the industrial and agricultural activities in their catchment areas. The quantification of the input of harmful substances into the Baltic Sea requires the complex hydrological conditions of

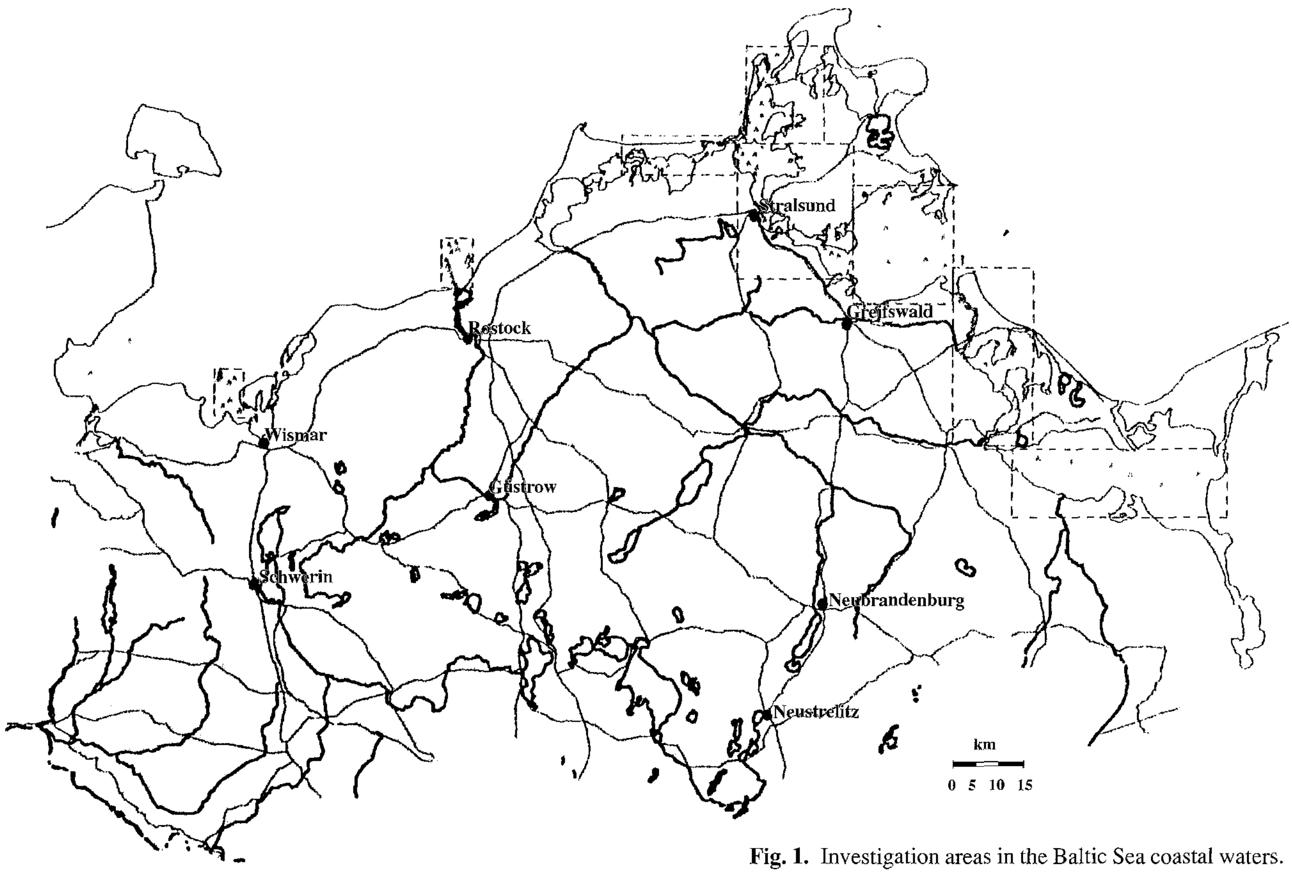

Fig. 1. Investigation areas in the Baltic Sea coastal waters.

some of the estuaries to be taken into account (HELCOM 1993). In terms of quality, however, the anthropogenic effects can be shown by the condition of the sediments in the coastal sections selected for examination. With regard to the natural structure of the Baltic coast and the main input roads for harmful substances, the following coastal sections (see Fig. 1) have by now been included in our investigation:

Wismarbucht, Warnow Estuary, Darss-Zingst chain of Boddens, Rügen Boddens, Strelasund, Greifswald Bodden, Stettin Lagon.

Regarding the Warnow Estuary, only its outer part is covered by the investigation since its inner part (the Breitling) is too heavily affected by local influences, such as the shipyard, ferryboat traffic, and the sewage purification plant of the city of Rostock and consequently requires separate examination (BACHOR 1989). Table 1 shows the geographic coordinates of the sections covered by the investigation.

Material and Methods

In view of the observed rates of deposition of 1.5–2 mm/a (ERLENKEUSER et al. 1974), investigations into the natural background would require sampling depths of at least 0.5 m. On the other hand the acquisition of data regarding the local variability of current regional pollution as a function of time requires periodical sampling of surface sediments only up to about 20 cm in depth.

The sampling sites we used have been shown to be representative in long-year series of measurements of water quality (LAUN 1991–1993). In addition, the sampling sites have been chosen in order to record anthropogenic influences without the measurements being directly affected by local discharges (see Table 1).

The samples were taken by means of van-Ween grab buckets and Reineck samplers. For comparison, depth soundings were made at selected points, using Niemistö corer and Rumor sounder.

The sediments in the various coastal sections are different for geogenic reasons and/or because of anthropogenic influences. In order to standardize the data, the nutrient content was evaluated according to the Redfield relationship (REDFIELD et al. 1963). The heavy metal data were normalized by determining them in the fraction of less than 20 µm which had been seperated by the method described by ACKERMANN (1980). The concentrations of organic contaminants were interpreted with respect to the total organic carbon content (TOC) and the fine particle-size portion.

The structural properties of the sediments are described in terms of their particle-size distribution and the total organic part (TOC). Nutrients include the total content of phosphorus and nitrogen.

The selected harmful-substance parameters refer to the lists of priority substances which are covered by special provisions of the Helsinki Convention (HELCOM 1992). Heavy metals (Hg, Cd, Cu, Cr. Ni, Pb, Zn) and arsenic (As) are given as concentrations in the fine particle-size fraction of less than 20 µm.

Table 1. Baltic Sea coastal waters.

Section	Position		Time period	Material
	N	E		
Wismarbucht	54° 01' 10" 53° 58' 35"	11° 18' 00" 11° 19' 25"	1992	sand
Warnow Estuary	54° 14' 00" 54° 11' 20"	12° 04' 00" 12° 05' 25"	1992–95	sand
Darss chain of Boddens	54° 24' 35" 54° 26' 15"	12° 40' 00" 13° 02' 25"	1992	silty sand
Rügen Boddens	54° 36' 25" 54° 23' 40"	13° 10' 15" 13° 06' 35"	1992	sand
Strelasund	54° 23' 40" 54° 12' 20"	13° 06' 35" 13° 24' 30"	1992–95	silt
Greifswald Bodden	54° 12' 20" 54° 16' 05"	13° 24' 30" 13° 44' 10"	1992–95	sand
Peenestrom	54° 09' 30" 53° 51' 25"	13° 44' 30" 13° 49' 10"	1993	sand
Stettin Lagoon	53° 50' 40" 53° 40' 30"	13° 51' 30" 14° 31' 30"	1992–95	silty sand

The organic harmful substances include mineral oil hydrocarbons (MH), polycyclic aromatic hydrocarbons (PAHs), chlorinated pesticides (HCH, DDT), hexachlorbenzene (HCB), and polychlorinated biphenyls (PCBs). PAHs, chlorinated pesticides, and PCBs are discussed in terms of their total amounts represented by the sums of 16 individual PAH-compounds according to EPA 610, of α- and γ-HCH, of o,p- and p,p-DDT and its DDD and DDE metabolites, and of the PCB-congeners 28, 52, 101, 138, 153, 180, respectively. The results for organic contaminants refer to the whole sample (<2 mm).

Results

Structural properties

In sediments, it is especially the distribution of heavy metals that depends on the particle size of the sediment (Hellmann 1986). The distribution of organic harmful substances depends mainly on the TOC not being a subject of grain size distribution and also the percentage of fine particles in the sediment. Consequently, structural properties are first of all discussed in terms of grain size distribution and organic carbon content (TOC).

In the examined district, the percentage of silt (<63 µm) varies between 20 and 65. In terms of mean values, the sediments in the Strelasund and in the Greifswalder Bodden have the highest percentage of silt. The sediments in the Darss chain of Boddens, in the Rügen Boddens, in the Peenestrom, and in the Stettin Lagoon have a mean silt content of 60%, The sediments in the Wismarbucht and in the outer region of the Warnow Estuary are described by the lowest percentage of silt of only 10%, respectively. The mean TOC varies between minimum 2.4 mg/g in the Warnow Estuary and maximum 70 mg/g in the Peenestrom (see Table 2).

Nutrients

Table 2 shows the values for the total phosphorus (P) and nitrogen (N) contents in combination with the TOC. The nitrogen to phosphorus-ratio tends to be higher the more to the east a coastal section is. Maximum amounts of nutrients were found in the Stettin Lagoon, namely 1.6 mg/g of P and 9.9 mg/g of N, which is due to the substance input from the river Oder and from the city and seaport of Stettin.

With regard to the bioavailable portions nutrient distribution in marine plankton had been described by Redfield et al. (1963) in terms of ranges for the C:P and N:P ratios. Assuming a similar situation on the seabed these relations in the sediments should be comparable.

In the most sediments the averaged C:P and N:P relations we found cover the ranges of 35 up to 140 and 6 up to 15, respectively. Taking into account the applied analytical methods and the matrices these values show a satisfactory agreement with the Redfield relations. An exception thereto is the sediment in the region of the Warnow Estuary, which is mainly sandy.

If the examined coastal sections were classified by their nutrient status, the outer Warnow Estuary, the Rügen Boddens, the Wismarbucht, the Darss chain of Boddens, and the Strelasund would rank in one group of comparable nutrient concentrations. Compared with these coastal sections, the

Table 2. Baltic Sea coastal waters. Nutrients.

Section		TOC [mg/g]	N [mg/g]	P [mg/g]	Redfield ratio C	: N	: P
Wismarbucht	Min	3.1	0.0	0.2	16	0	1
	Max	113.3	2.7	0.7	162	3.9	1
	Ave	39.6	0.9	0.4	99	2.3	1
	Sample	12	12	12			
Warnow Estuary	Min	0.2	0.0	0.1	2	0	1
	Max	22.2	2.0	0.5	44	4	1
	Ave	2.4	0.7	0.3	8	2.3	1
	Sample	13	10	10			
Darss chain of Boddens	Min	4.1	0.3	0.1	41	3	1
	Max	105.2	13.1	1.0	105	13.1	1
	Ave	43.2	5.2	0.4	85.5	13	1
	Sample	8	12	12			
Rügen Boddens	Min	4.1	0.4	0.2	21	2	1
	Max	35.1	4.0	0.5	70	8	1
	Ave	16.9	1.9	0.3	56.3	6.3	1
	Sample	4	15	15			
Strelasund	Min	17.3	2.2	0.3	58	7.3	1
	Max	68.5	8.6	2.0	34	4.3	1
	Ave	49.4	5.7	0.8	62	7.1	1
	Sample	11	19	19			
Greifswald Bodden	Min	0.7	0.1	0.1	7	1	1
	Max	49.8	2.7	0.4	125	6.8	1
	Ave	28.2	1.2	0.2	141	6	1
	Sample	14	13	13			
Peenestrom	Min	3.7	0.0	0.1	37	0	1
	Max	115	16.0	3.3	35	4.9	1
	Ave	70	9.0	0.6	117	15	1
	Sample	9	9	21			
Stettin Lagoon	Min	13.5	5.9	0.5	27	11.8	1
	Max	85.2	15.0	4.1	240	3.7	1
	Ave	5.2	9.9	1.6	35	6.2	1
	Sample	6	6	6			
Redfield et al. (1963)					116	16	1

Stettin Lagoon and the Peenestrom have exceptionally high concentrations of nutrients.

Other authors with different approaches arrived at comparable results for the investigated coastal sections (Brügmann 1995; Lampe 1994; Leipe et al. 1995).

Heavy metals

As mentioned above, for a comparative consideration of the pollution with heavy metals the mean concentrations in the fine particle-size fraction were used. Table 3 gives a general survey for all heavy metals measured and for As. Obviously, the examined coastal sections can be divided into three groups; first, the Wismarbucht, Darss chain of Boddens, the outer estuary of the Warnow, and the Peenestrom; second, the Rügen Boddens, the Strelasund and the Greifswald Bodden; and third, the Stettin Lagoon, which because of its significantly higher concentrations has a outstanding position. The heavy metal concentrations, especially as far as Hg, Cd, Cu, Pb, and Zn are concerned, tend to be lower in the western coastal sections and higher in the eastern ones. Our results correspond to the data of other references (Brügmann 1995; Neumann et al. 1989; Leipe et al. 1995).

The mean heavy-metal concentrations in the sediments of the examined coastal sections of the Baltic Sea compare with the mud flats of the North Sea (HABAK 1992) by factors of between 0.05 and 4. Generally, the sediments in most of the examined sections of the Baltic coast are less polluted by the majority of the elements analyzed. The only exceptions are copper and zinc showing clearly higher concentrations at the Baltic coast, most probably due to the run-offs from sewage purification plants.

Compared with the North Sea, the conditions at the baltic coast are of much greater variability. Thus the Baltic

Table 3. Baltic Sea coastal waters. Heavy metals (fine grain fraction).

Section		Hg [µg/g]	Cd [µg/g]	As [µg/g]	Ni [µg/g]	Cr [µg/g]	Cu [µg/g]	Pb [µg/g]	Zn [µg/g]
Wismarbucht	Min	0.03	0.01	4.7	20	21	35	26	92
	Max	0.5	1.3	9.9	37	55	54	74	254
	Ave	0.24	0.25	7	27	35	46	58	174
	Sample	12	12	12	12	12	12	12	12
Warnow Estuary	Min	0.11	<1	5.9	19	29	22	25	124
	Max	0.5	1.5	9.5	42	66	36	51	237
	Ave	0.26	1	7.5	29	42	29	33	160
	Sample	10	10	10	10	10	10	10	10
Darss chain of Boddens	Min	0.2	<1	3.7	18	29	18	27	134
	Max	0.9	2	9.8	43	63	32	56	894
	Ave	0.4	1.1	6	27	41	26	40	251
	Sample	12	12	12	12	12	12	12	12
Rügen Boddens	Min	0.3	0.7	<5	22	33	24	24	86
	Max	0.7	3.6	10	80	54	44	265	538
	Ave	0.5	1.7	6.4	35	43	33	63	222
	Sample	15	15	15	15	15	15	15	15
Strelasund	Min	0.2	<1	6.9	29	32	26	36	136
	Max	1.2	2.6	13	52	59	49	89	358
	Ave	0.4	1.7	9.6	38	50	36	68	228
	Sample	19	19	19	19	19	19	19	19
Greifswald Bodden	Min	0.4	2.8	14	36	47	41	70	297
	Max	0.5	5.1	25	58	63	68	93	512
	Ave	0.4	3.4	17	43	54	52	78	371
	Sample	13	13	13	13	13	13	13	13
Peenestrom	Min	0.19	<0.5	11	29	33	33	22	134
	Max	0.48	5.1	19	40	54	58	83	288
	Ave	0.39	2.1	15	35	44	44	58	288
	Sample	15	15	15	15	15	15	15	15
Stettin Lagoon	Min	0.5	2.9	21	36	52	52	103	534
	Max	1.18	5.3	30	45	73	67	161	981
	Ave	0.8	4.4	24	40	62	66	130	799
	Sample	6	6	6	6	6	6	6	6

coast requires a different approach in deriving quality criteria.

Organic harmful substances

Table 4 summarizes appropriate data for organic contaminants. The total content of PAHs is less than 1 µg/g in most of the coastal sections. The total range is 0.2 to 3.3 µg/g. Clearly higher concentrations were found in the eastern sections Strelasund, Peenestrom, and Stettin Lagoon. A comparative statement can also be made for the content of mineral oil hydrocarbons. Here the range of variation is 10–120 µg/g, while the highest concentrations appear again in the three sections mentioned above.

For PCBs, DDTs, and HCHs, low contents are to be found. Furthermore, the ratio between the highest and lowest values varies between 3 and 4. Therefore, these concentrations should have little effect on the differentiation between the individual sections. In the case of HCB the mean concentrations are also low. On the other hand this parameter shows a relatively high variability between 0.3 and 3.4 ng/g. The largest mean concentration of HCB was found in the Stettin Lagoon, being another indicator for the anthropogenic pollution in this region.

In terms of TOC, the sections Wismarbucht, Darss chain of Boddens, Strelasund, Peenestrom, and Stettin Lagoon are at a comparable level (30–50 mg/g); the outer estuary of the Warnow and the Greifswald Bodden have the lowest concentrations (about 5 mg/g); and the Rügen Boddens (15 mg/g) have an intermediate position, as shown by Table 2. Considering the organic contaminants in relation to the organic carbon content, one can say that a significant correlation exists only between TOC and DDT. Thus, the differences between the individual sections cannot be explained solely by the differences in TOC.

Table 4. Baltic Sea coastal waters. Organic harmful substances.

Section		Total PAH EPA [µg/g]	MH [µg/g]	Total DDT [ng/g]	Total HCH [ng/g]	HCB [ng/g]	Total PCB [ng/g]
Wismarbucht	Min	0.84	10	4	2.9	0.2	7.8
	Max	0.93	33	4	3.6	0.6	8.7
	Ave	0.89	16	4	3.3	0.4	8.3
	Sample	2	9	2	2	2	2
Warnow Estuary	Min	0.29	1	2.2	2	0.4	3.5
	Max	1.3	28	11	4.4	2.8	29
	Ave	0.66	8	6.6	2.6	1.3	12
	Sample	9	12	7	7	7	7
Darss chain of Boddens	Min	0.15	1	3.9	1.2	0	6.5
	Max	0.18	1	23	3	0.8	27
	Ave	0.16	1	13	2.4	0.3	15
	Sample	7	7	7	7	7	7
Rügen Boddens	Min	0.15	1	3	1.9	0	5.6
	Max	1.16	1	27	7	3.8	26
	Ave	0.49	1	13	4.3	0.8	16
	Sample	8	5	9	9	9	9
Strelasund	Min	0.15	1	8.5	3.1	0	9.3
	Max	1.86	101	25	4	1.4	48
	Ave	0.72	23	16	3.8	0.7	24
	Sample	8	12	8	8	8	8
Greifswald Bodden	Min	0.15	1	0.7	0	0	1.5
	Max	2.19	59	27	4	6.5	85
	Ave	1.12	30	11	1.8	0.9	20
	Sample	21	15	24	23	23	24
Peenestrom	Min	0.86	1	3.5	2.5	0.4	9.4
	Max	1.48	125	6.1	2.7	0.5	19
	Ave	1.17	32	4.8	3.2	0.4	14
	Sample	2	4	2	2	2	2
Stettin Lagoon	Min	0.15	1	0.8	0.8	0.3	0
	Max	7.42	375	50	8.8	15	58
	Ave	3.19	100	16	2.3	3.6	19
	Sample	19	38	33	33	33	34

The data of Table 4 suggest that with respect to organic contaminants there is one group with comparable, low pollution (outer Estuary of the Warnow, Wismarbucht, Greifswald Bodden; Rügen Boddens, and Darss chain of Boddens) and another group with greater pollution (Strelasund, Peenestrom, and Stettin Lagoon).

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